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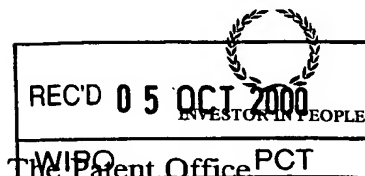
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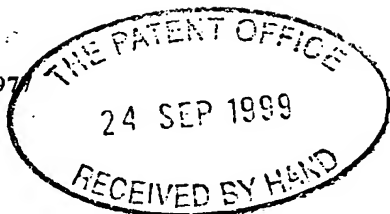
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4. Title of the invention

Method and Apparatus for Producing Semisolid Metal Slurries and Shaped Components

5. Name of your agent (if you have one)
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Williams, Powell & Associates
4 St. Paul's Churchyard
London
EC4M 8AY

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Method and Apparatus for Producing Semisolid Metal Slurries and Shaped Components

This invention relates to an apparatus and method for forming a shaped component from liquid metal alloy. In particular, it relates to a method and apparatus for converting liquid metal into semisolid slurry which is injected subsequently into a die cavity to produce shaped components. The apparatus and method are applicable to light alloys, such as aluminium alloy, magnesium alloy, zinc alloy and any other alloy suitable for semisolid processing.

One of the conventional methods for manufacturing metallic components is die casting. In the conventional die casting process, the liquid metal is usually forced into a mould cavity at such a high speed that the flow becomes turbulent or even atomised. As a result, air is often trapped within the cavity, leading to high porosity in the final components, which reduces the component strength and can cause component rejection if holes appear on the surface after machining. Moreover, components with high porosity are unacceptable because they are usually not heat-treatable, thus limiting their potential applications.

Intuitively, the porosity due to turbulent or atomised flow could be reduced or even eliminated if the viscosity of the metal flow could be increased to reduce the Reynolds number sufficiently so trapped air is minimised, somewhat similar to the injecting moulding of plastics. However, it was not clear how this could be achieved until the early 1970s when Metz and Flemings proposed the concept of semisolid metal (SSM) processing. They suggested that, if solidification is carried out in the semisolid state, the porosity of castings could be reduced significantly. The study of Spencer et al showed that when molten metal is agitated during cooling below its liquidus temperature, the dendritic primary solid particles would be broken into near spherical particles suspended in the liquid metal matrix. The exponentially increased viscosity with the solid fraction of such a semisolid slurry can produce sound castings with die casting process. The SSM

process improves upon the die casting method by injecting semisolid metal rather than fully liquid metal into a die cavity for component production. Compared with conventional die casting routes, SSM processing has the following advantages: (1) cost effectiveness over the whole manufacturing cycle; (2) near-net shape processing; (3) consistency and soundness of mechanical properties; (4) ability to make complex component shapes; ~~(5) weight reduction through alloy substitution and more efficient use~~ of materials; (6) high production rate; (7) enhanced die life; (8) less environmental cost. The enhanced mechanical properties result from the improved microstructural features, such as refined grain size, non-dendritic morphology and substantially reduced porosity level.

Although the concept of SSM processing seems promising, the major problem remains as how the slurry is produced and how the component is shaped efficiently. Since the early 1970s, a number of alternatives to the original MIT rheocasting process have been developed. One of the most popular processes currently used is thixoforming, in which pre-processed nondendritic alloy billet are reheated to the semisolid region prior to the shaping process. It is therefore a two-stage process. The high cost of pre-processed nondendritic raw materials is by far the greatest obstacle to the development of the full potential of this approach. In addition, plastic injection moulding techniques have recently been introduced into the SSM processing field. One process is "thixomoulding" for Mg-alloys, which was developed by Dow Chemicals and currently marketed by Thixomat, the other one was developed at Cornell University (USA) for Sn-Pb alloys. In both cases, a single screw extruder was used. However, a single screw extruder offers neither positive displacement pumping action nor the high shear rate required by SSM processing. Therefore, the quality of both semisolid slurries and final components is not totally satisfactory.

During the last 20 years, the most active method of producing semisolid slurry is mechanical agitation. Unfortunately, most mechanical stirring methods have not gained popularity in industry because of the problems associated with erosion of the stirring

device, problems with synchronisation of the stirring with the continuous casting process, and the inadequate shear rate to obtain fine particles.

Therefore, the primary objective of this invention is to provide an apparatus and method which converts liquid alloy into its thixotropic state and fabricates high integrity components by injecting subsequently the thixotropic alloy into a die cavity in an integrated one-step process.

Another objective of the invention is to provide an apparatus and method which is specially adapted for producing semisolid alloys with a highly corrosive and erosive nature in their liquid or semisolid state.

Still another objective of the invention is to provide an improved die casting system suitable for production of high integrity components from semisolid slurry.

Briefly described, these and other objectives are accomplished according to the present invention by providing an apparatus and method to produce high integrity components from liquid alloys. In the invented process the steps of melting the alloy, converting the alloy into its thixotropic state and injecting the thixotropic alloy into a die cavity are carried out at physically separated functional units. The invented apparatus consists of a liquid metal feeder, a high shear twin-screw extruder, a shot assembly and a central control system. The rheomoulding process starts from feeding liquid metal from the a liquid metal feeder into a twin-screw extruder. The liquid metal is rapidly cooled to the SSM processing temperature in the first part of the extruder while being mechanically sheared by twin-screws, converting the liquid alloy into a semisolid slurry with a pre-determined volume fraction of the solid phase dictated by accurate temperature control. The semisolid slurry is then injected at a high velocity into a mould cavity. The fully solidified component is finally released from the mould. All these procedures are performed in a continuous cycle and controlled by a central control system.

In a first aspect of the invention, there is provided a method for forming a shaped component from liquid metal alloy, comprising the steps of transferring the liquid metal alloy into a temperature-controlled extruder, operating the extruder at a sufficiently high shear rate to convert the alloy to its thixotropic state, and subsequently transferring the alloy into a mould to form the shaped component, wherein the extruder is any extruder which is capable of providing sufficiently high shear to enable the alloy to be converted to its thixotropic state and which can provide a positive displacement pumping action.

Preferably, the extruder is a twin-screw extruder.

In a second aspect of the invention, there is provided apparatus for forming a shaped component from liquid metal alloy, comprising a temperature-controlled twin screw extruder able to impart sufficient shear to a liquid metal alloy to convert it to its thixotropic state, a shot assembly in fluid communication with the extruder, and a mould in fluid communication with the shot assembly.

The said method can offer semisolid slurries with fine and uniform solid particles and with a large range of solid volume fractions (15% to 85%). The said apparatus and method can also offer net-shaped metallic components with the porosity being close to zero. The said method preferably comprises the steps of:

- (a) providing said alloy in the liquid state and pouring said liquid alloy to a temperature-controlled extruder through a feeder;
- (b) converting said liquid alloy to its thixotropic state by the high shear rate offered by the twin-screws;
- (c) transferring said thixotropic alloy from the extruder into a shot sleeve by opening a control valve located at one end of the extruder; and
- (d) injecting said thixotropic alloy from the shot sleeve into a mould cavity by an advancing piston at high speed.

Generally, the feeder is used to supply liquid alloy at the desired temperature to the twin-screw extruder. The feeder can be a melting furnace or just a ladle.

Generally, the twin-screw extruder, consisting of a barrel, a pair of screws and a driving system, is adapted to receive molten alloy through an inlet located generally toward one end of the extruder. Once in the passageway of the twin-screw extruder, molten alloy is either cooled or maintained at a predetermined temperature. In either situation, the processing temperature is above the alloy's solidus temperature and below its liquidus temperature so that the alloy is in the semisolid state in the extruder.

The processing temperature, which as stated depends upon the liquidus and solidus temperatures of the alloy, will vary from alloy to alloy. The appropriate temperature will be apparent to one skilled in the art. As an example, for the alloy Al-7%Si-0.5%Mg (that is aluminium with 7% w/w silicon and 0.5% w/w magnesium), the alloy should be poured into the extruder at a temperature of from 650°C to 750°C, and should be processed in the extruder at a temperature of from 560°C to 610°C.

Also in the twin-screw extruder, the alloy is subjected to shearing. The shear rate is such that it is sufficient to prevent the complete formation of dendritic shaped solid particles in the semisolid state. The shearing action is induced by a pair of screws located within the barrel and is further invigorated by a helical screw flights formed on the body of the screws. Enhanced shearing is generated in the annular space between the barrel and the screw flights and between the flights of two screws. The positive displacement pumping action of the twin-screw can also cause the thixotropic alloy to travel from the inlet of the extruder toward the outlet of the extruder, where it is discharged.

The interior environment of the twin-screw extruder is characterised by high wear, high temperature and complex stresses. The high wear is a result of the close fit between the barrel and the twin-screw as well as between the screws themselves. Therefore, a suitable material for the barrel and screws or any other components must exhibit good

resistance to wear, high temperature creep and thermal fatigue. The interior environment of the twin-screw extruder is also highly corrosive and erosive. This is caused by the high reactivity of liquid or semisolid metals such as aluminium which can dissolve and/or erode most metallic materials. After intensive tests and evaluation, the present invention

5 has developed a novel machine construction which allows highly corrosive and erosive materials, such as aluminium and zinc alloys, to be conditioned into their thixotropic state without any significant degradation of the machine itself.

The barrel of the twin-screw extruder is constructed with an outer layer of creep resistant

10 first material which is lined by an inner layer of corrosive and erosive resistant second material. Preferably, the outer layer material is H11, H13, or H21 steels and the inner layer material is Sialon. Bonding of the inner layer and outer layer is achieved by either shrink fitting or with a buffer layer between the two.

15 The twin-screw is positioned within the passageway of the twin-screw extruder. The rotation of the twin-screw subjects the molten alloy to high shear and to translate the material through the barrel of the extruder. The screw is constructed with Sialon components that are mechanically or physically bonded together to gain maximum resistance to creep, wear, thermal fatigue, corrosion and erosion. Additional components

20 of the extruder, including the outlet pipe, outlet valve body and valve core, are also constructed from Sialon. The twin-screw extruder is driven by either an electrical motor or hydraulic motor through a gearbox to maintain the desired rotation speed.

The shot sleeve, located in shot assembly of the rheomoulder, can receive the semisolid

25 slurry from the extruder. The thixotropic alloy in the shot sleeve can be injected at high speed to a die cavity by a fast moving piston through the cylinder.

Additional objectives and advantages of the invention will be set forth in the description which follows. The objectives and advantages of the invention may be realised and

obtained through instrumentalities and combinations of particular points described in the appended claims.

Preferred embodiments of the invention are described in detail below with reference to the drawings, in which:

Fig 1 is a schematic illustration of an embodiment of an apparatus for converting liquid alloys into a thixotropic slurry and for producing high integrity components according to the principles of the present invention.

Fig 2 is a schematic cross-sectional view of the twin-screw and barrel according to the principles of the present invention.

Fig 3 is a sectional illustration of a screw constructed according to the principles of the present invention.

Fig 4 shows the microstructures of rheomoulded Sn-15%Pb alloys of different solid volume fraction.

In the description of the preferred embodiment which follows, a die casting is produced by a twin-screw rheomoulding machine from aluminium (Al) alloy ingot. The invention is not limited to Al alloys and is equally applicable to any other types of alloys, such as magnesium alloys, zinc alloys and any other alloy suitable for semisolid metal processing. Furthermore, specific temperatures and temperature ranges cited in the description of the preferred embodiment are only applicable to Al-alloys, but could be readily modified in accordance with the principles of the invention by those skilled in the art in order to accommodate other alloys.

Fig 1 illustrates a twin-screw rheomoulding system 10 according to an embodiment of this invention. The system 10 has three sections: a feeder 20, a twin-screw extruder 30

and a shot assembly 40. A liquid alloy is supplied to the feeder 20. The feeder 20 is provided with a plunger 21, a socket 22 and a series of heating elements 23 disposed around the outer periphery of the crucible 24. The heating elements 23 may be of any conventional type and operates to maintain the feeder 20 at a temperature high enough to keep the alloy supplied through the feeder 20 in the liquid state. For Al-alloys, this temperature would be over 600°C. The liquid alloy is subsequently fed into the twin screw extruder 30 by way of gravity when the plunger 21 is optionally raised.

The extruder 30 has a plurality of heating elements 31, 33 and cooling channels 32, 34 dispersed along the length of the extruder 30. The matched heating elements 31, 33 and cooling channels 32, 34 form a series of heating and cooling zones respectively. The heating and cooling zones maintain the extruder at the desired temperature for semisolid processing. For a rheomoulding system 10 designed for Al-alloys, heating and cooling elements 33 and 34 would maintain the top part of the extruder at a temperature of about 585°C; and heating and cooling elements 31 and 32 would maintain the bottom part of the extruder at a temperature of about 590°C. The heating and cooling zones also make it possible to maintain a complex temperature profile along the extruder axis, which may be necessary to achieve certain microstructural effects during semisolid processing. The temperature control of each individual zone is achieved by balancing the heating and cooling power inputs by a central control system. The methods of heating can be resistance heating, induction heating or any other means of heating. The cooling media may be water or gas depending on the process requirement. While only two heating/cooling zones are shown in Fig 1, the extruder 30 can be equipped with between 1 to 10 separately controllable heating/cooling zones.

The extruder 30 also has a physical slope or an inclination. The inclination is usually between 0-90° and preferably between 20-90° relative to the shot direction. The inclination is designed to assist the transfer of semisolid alloy from the extruder 30 to the shot sleeve 42.

The extruder 30 is also provided with a twin-screw 36 which is driven by an electric motor or hydraulic motor 25 through a gear box 26. The twin-screw 36 is designed to provide high shear rate which is necessary to achieve fine and uniform solid particles. Different types of screw profiles may of course be used. In addition, any device which
5 offers high shear mixing and positive displacement pumping actions may also be used to replace the twin-screw.

The thixotropic alloy exits the extruder 30 into a shot assembly 40 through a valve 39. The valve 39 operates in response to a signal from the central control system. The
10 optional opening of valve 39 should match the process requirements. Injection of the thixotropic alloy is made by a piston 41 through the shot sleeve 42 into a mould cavity 45. The position and velocity of piston 41 are adjustable to suit the requirement by different processes, materials and final components. Generally, the shot speed should be high enough to provide enough fluidity for complete mould filling, but not too high to
15 cause air entrapment.

As shown in Fig 1, heating elements 43 and 44 are also provided along the length of the shot sleeve 42. Heating elements referenced and prefixed herein are resistance elements. In the preferred embodiment of the rheomoulding system for processing Al-alloys, the
20 shot sleeve is preferably maintained at a temperature close to the extruder temperature to maintain the alloy in its predetermined semisolid state.

Fig 2 is a schematic sectional illustration of the barrel as used in the preferred embodiment, which consists of an outer tool steel shell 37 and a Sialon liner 38. The
25 Sialon liner 38 can be shrink fitted into the outer layer 37 using the difference of coefficients of thermal expansion between tool steel and Sialon. The temperature for shrink fitting the cold Sialon liner 38 into the heated steel shell is chosen in such a way that a tight fit between the barrel and its liner is achieved at the processing temperature to guarantee efficiency for heat transfer. Sialon is chosen here as the barrel liner to provide
30 good resistance to wear, corrosion and erosion, while retaining the necessary strength

and toughness at the processing temperature. For barrels of small sizes, a monolithic Sialon construction of the barrel may be utilised.

Fig 3 is a sectional illustration of a screw constructed according to the principles of the present invention. The screw 36 for the rheomoulding system 10 can be fabricated as a mechanical assembly of Sialon screw sections. The components 46, 48 with desired profile are assembled together and then installed onto shaft 47 to achieve required alignment. Preferably, a tight assembly with a small tolerance should be used. For screws of small sizes, a monolithic Sialon screw may be utilised.

Fig 4 illustrates the microstructures of the rheomoulded Sn-15%Pb alloy (that is, tin with 15% lead by weight) processed at different processing conditions. Specifically, the upper photograph illustrates the microstructure of an alloy having 40% solid volume fraction, and the lower photograph illustrates the microstructure of an alloy having 80% solid volume fraction. The photographs indicate that the invented twin-screw rheomoulding process is capable of producing semisolid slurries with fine equiaxed solid particles and a large range of solid volume fraction. In particular, with proper die design, the developed process is capable of manufacturing net-shape components with close to zero porosity.

The embodiment may also contain a device attached to the extruder 30 to supply protective gas in order to minimise oxidation. Such a gas may be argon or nitrogen.

Generally, the rheomoulding system has a central control system to control all the functions. Preferably, the control system is programmable so that the desired solid volume fraction in the semisolid state may be achieved easily. The control system (not shown in Fig 1) may, for example, comprise a microprocessor which may be easily and quickly reprogrammed to change the processing parameters.

While this particular embodiment according to the invention have been illustrated and described above, it will be clear that the invention can take a variety of forms and embodiments within the scope of the appended claims.

CLAIMS

1. A method for forming a shaped component from liquid metal alloy, comprising the steps of:
 - 5 transferring the liquid metal alloy into a temperature-controlled extruder,
operating the extruder at a sufficiently high shear rate to convert the alloy to its
thixotropic state, and
subsequently transferring the alloy into a mould to form the shaped component,
wherein the extruder is a twin-screw extruder.
- 10 2. A method as claimed in claim 1, wherein, prior to being transferred into the mould, the alloy is transferred into a shot assembly which injects the alloy into the mould.
- 15 3. A method as claimed in claim 1 or 2, wherein the temperature of the alloy whilst it is in the extruder is maintained between the liquidus and solidus temperatures of the alloy, such that the alloy is in a semisolid state.
- 20 4. A method as claimed in claim 3, wherein the solid volume fraction in the alloy whilst it is in the extruder is from 15 to 85%.
5. Apparatus for forming a shaped component from liquid metal alloy, comprising a temperature-controlled twin-screw extruder able to impart sufficient shear to a liquid metal alloy to convert it to its thixotropic state, a shot assembly in fluid communication
25 with the extruder, and a mould in fluid communication with the shot assembly.
6. Apparatus as claimed in claim 5, additionally comprising a feeder for feeding the liquid metal alloy into the extruder.

7. Apparatus as claimed in claim 6, wherein the feeder has means for containing and maintaining the alloy at a temperature above the liquidus temperature.

8. Apparatus as claimed in any of claims 5 to 7, wherein the extruder has a barrel
5 and a pair of screws, the inner surface of said barrel and the outer surface of said screws
are resistant to corrosion and erosion by liquid alloys, said twin screws each including a
body having at least one vane thereon, said vane at least partially defining a helix around
said body to propel the alloy through said barrel.

9. Apparatus as claimed in any of claims 5 to 8, having an electric or hydraulic
10 motor for rotating said twin screws and shearing said alloy at a shear rate sufficient to
inhibit complete formation of dendritic structures therein while said alloy is in a
semisolid state, the rotation of said twin screws by said electric or hydraulic motor also
causing said alloy to be transported from one end to another end of said barrel.

10. Apparatus as claimed any of claims 5 to 9, including temperature controllable
15 means for transferring heat to said extruder barrel, said twin screws and said alloy
therein such that said alloy is in a semisolid state and at a temperature between the
liquidus and solidus temperatures of said alloy.

11. Apparatus as claimed in any of claims 5 to 10, including a control valve between
20 the extruder and the shot assembly for discharging said alloy from said extruder to a shot
sleeve in a cylinder-piston assembly.

12. Apparatus as claimed in any of claims 5 to 11, wherein the extruder barrel has an
25 inner layer which is mechanically bonded to an outer layer of said barrel by shrink
fitting.

13. Apparatus as claimed in any of claims 5 to 12, wherein said extruder barrel is a
30 monolithic component formed from Sialon ceramic.

14. Apparatus as claimed in any of claims 5 to 13, wherein all surfaces and the inner layer of said apparatus in contact with the semisolid alloy are formed from Sialon ceramic.

5

~~15. Apparatus as claimed in any of claims 5 to 14 wherein said outer layer of said barrel is tool steel H11, H13 or H21.~~

16. Apparatus as claimed in any of claims 5 to 15, wherein said screw is
10 mechanically bonded Sialon screw sections by shrink fit.

17. Apparatus as claimed in any of claims 5 to 16, wherein said screw is a monolithic construction of Sialon ceramic.

15 18. A method substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

19. Apparatus substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

Method and Apparatus for Producing Semisolid Metal Slurries and Shaped Components

ABSTRACT

5

A method and apparatus for converting liquid alloy into its thixotropic state and for fabricating high integrity components by injecting subsequently the thixotropic alloy into a die cavity. The apparatus includes a liquid metal feeder, a high shear twin-screw extruder, a shot assembly and a central control system. The apparatus and method can
10 offer net-shaped components characterised by close to zero porosity, fine and equiaxed particles with a uniform distribution in the eutectic matrix, and a large range of solid volume fractions.

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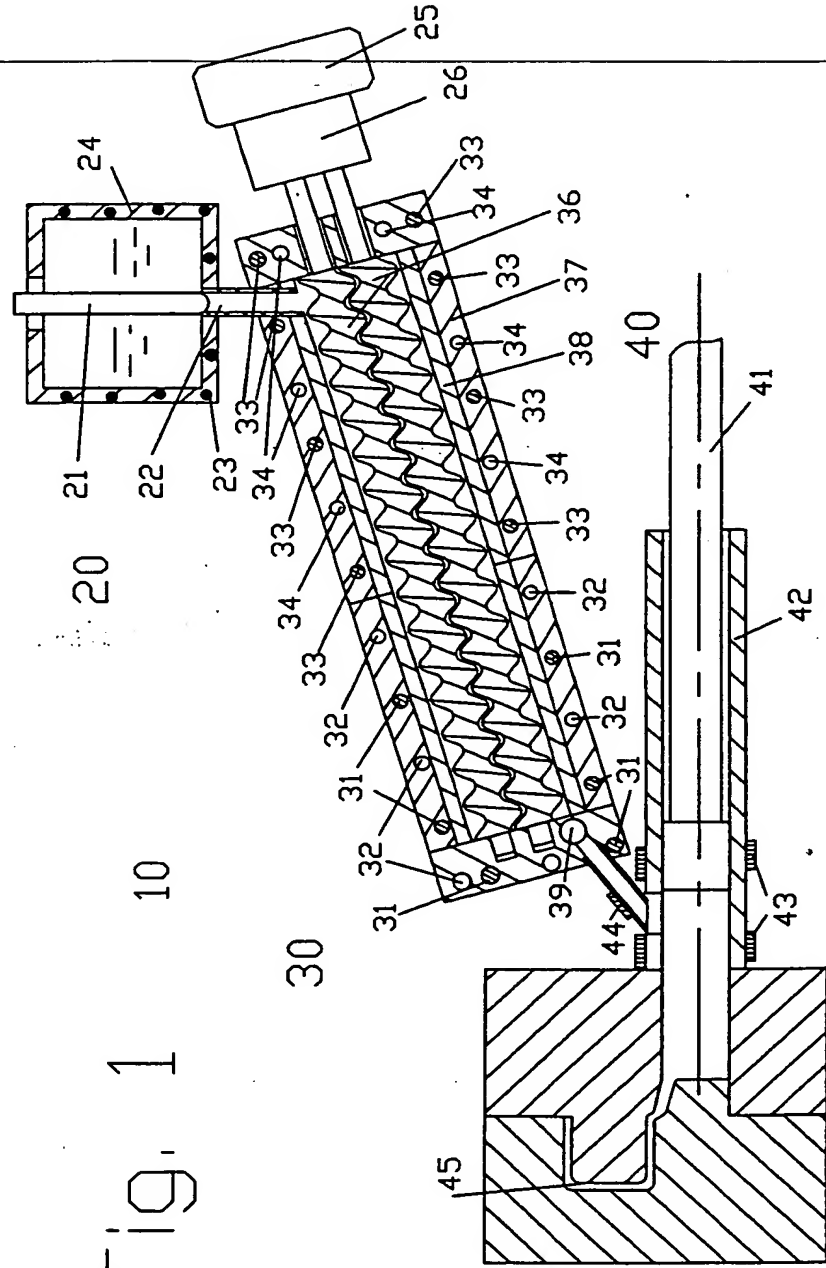


Fig. 1 10

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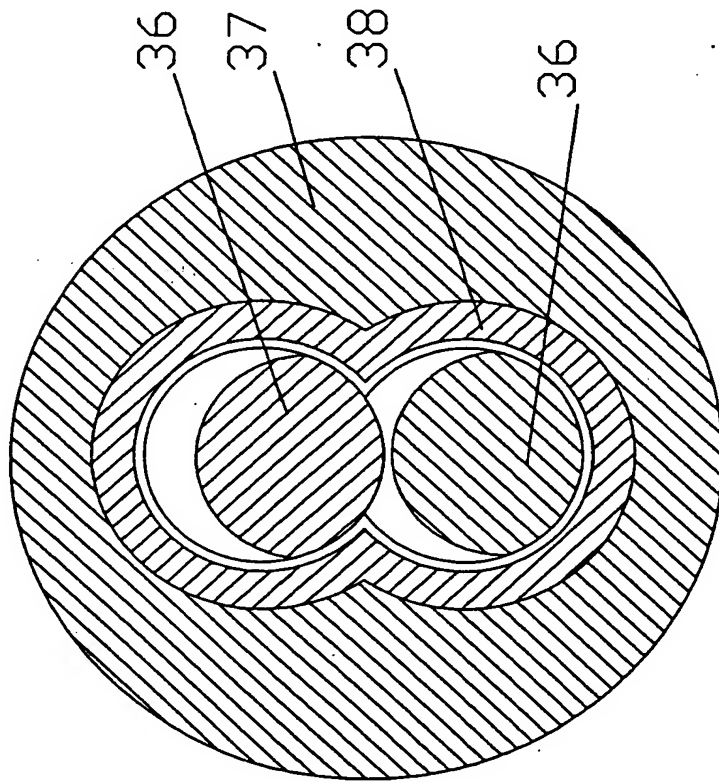


FIG. 2

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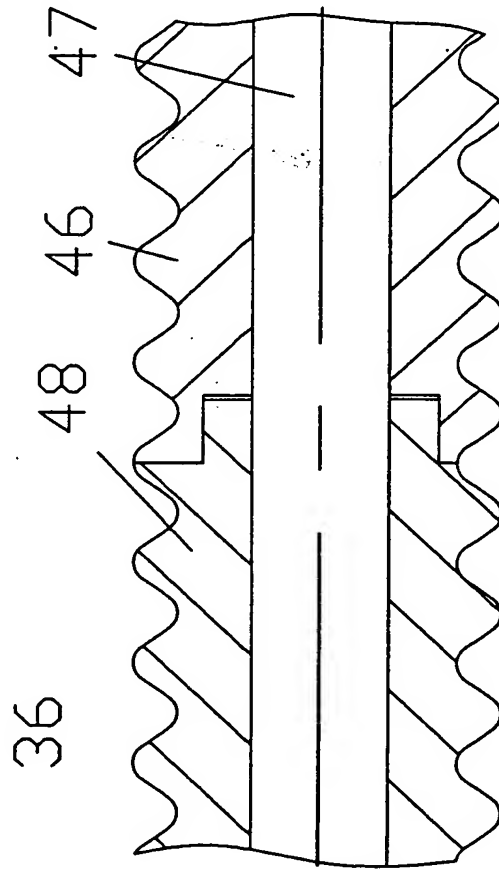


Fig. 3

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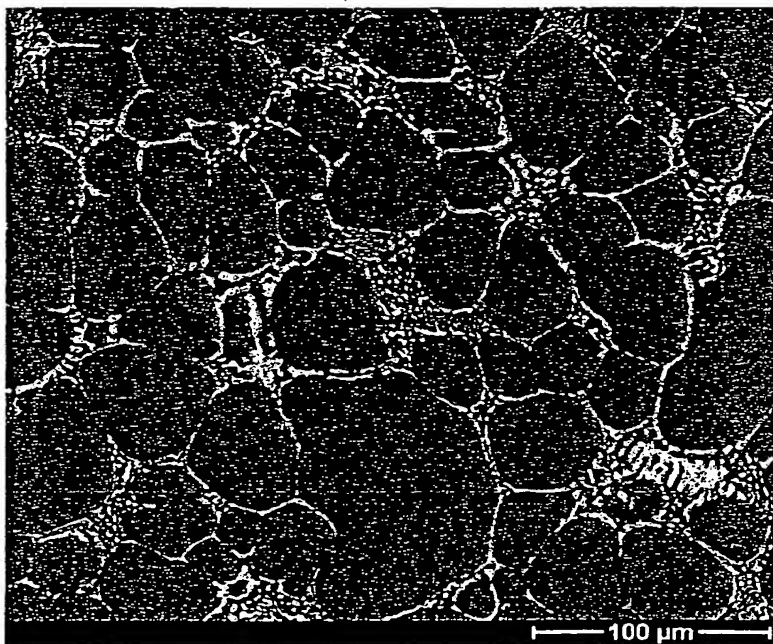
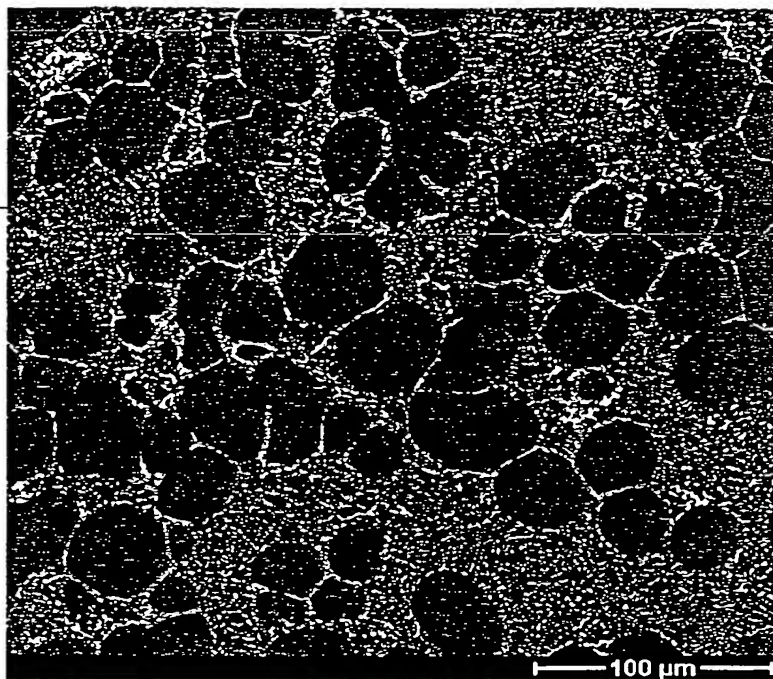


Figure 4.

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